AD658734

DESIGN OF TESTS FOR THE EFFECTS OF MASS FIRES ON SHELTER OCCUPANTS

FINAL REPORT

26 September 1966

Contract No. NOO 228 66C0917

OCD Work Unit No. 1133B

T. O. No. 65-200 (64)

ISOTOPES, INCORPORATED*

*formerly Hazleton-Nuclear Science Corp.

Palo Alto, California

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NRDL-TRC-67

DESIGN OF TESTS FOR THE EFFECTS OF MASS FIRES ON SHELTER OCCUPANTS

Summary of

Final Report

Isotopes, Inc. OCD Work Unit 1133B

It has been established that an outbreak of mass fires would introduce serious additional life hazard factors which may require extensive modifications or overhaul of our existing concepts of shelter design, construction and management. In order to fully understand the problems faced by shelter occupants in a mass fire environment and be able to devise and evaluate possible protective mechanisms, it is necessary to study in detail not only the characteristics of the mass fire itself, but also the various biological hazard factors affecting the shelter occupants. The USFS is conducting a series of field experiments to study the first problem. In this report are presented recommendations for an overall program of biological testing designed to satisfy the second requirement.

An extensive investigation was made to determine the nature of the actual life hazard factors affecting the shelter occupant exposed to the mass fire environment. Sources of this information included literature search, personal interviews, group discussions and meetings, and visits to actual burn sites. The known and predicted major life hazard factors are identified as (1) heat, (2) gases affecting respiration, (3) smoke, dust and other aerosols, (4) physiological, behavioral and human engineering factors. Known human and test animal responses to each of these factors are presented and the manner in which such biological responses would affect practical field test designs are discussed.

In any discussion of various biological hazard factors it is often convenient to divide these into (1) those that can be evaluated or predicted from simple physical measurements of the environment, and (2) those that require some accepted biological index or endpoint for proper detection, evaluation and measurement. Even simple physical measurements such as heat and oxygen level must, however, be designed and carried out with a proper understanding and control of all the other factors entering into the biological hazard problem; otherwise, such tests would lose most if not all of their potential value for hazard evaluation and protection purposes. (In this respect, measurements of potential hazard factors such as temperature, CO, CO_2, and O_2 made by field engineers, physical scientists and other non-biology oriented groups mainly for the purpose of testing the characteristics

of the mass fire itself are of perhaps limited usefulness except as very gross indicators.) Although many individual aspects of mass fire phenomenology can be simulated and studied in the laboratory, the overall effects can only be studied within the framework of large-scale field experiments such as Operation Flambeau. For this reason tests to study effects on shelters and shelter occupants as well as the development and evaluation of appropriate protective measures must be designed as integral parts of such field experiments.

On the other hand, it is also necessary to separate the various hazard factors into those which can be effectively evaluated under field conditions and those which require conditions not possible to reproduce in the field. Almost all the test designs suitable for field evaluation would require significant upgrading and improvement of present field facilities. (At present no field facilities for biological testing exist.)

Planning and formulation of successful biological field experiments require a thorough understanding of the basic principles of proper biological test design, and the precautions needed in order to avoid ambiguous results and erroneous conclusions. The practical application of such basic design considerations to representative examples of suitable field experiments is discussed. Even for the simplest tests of the "shotgun" variety, it is necessary to have mechanisms for adequate control of the many interacting variables. It is suggested that the single most important mechanism to provide the required controls would be the adoption of a standard test shelter design for all mass fire studies. Such a standardized test shelter would also serve as the necessary "connecting link" for normalizing and correlating work that is being done in the laboratory and elsewhere with the results of field experiments.

Report No. HNS-80

Date: 26 September 1966

Hazleton-Nuclear Science Corporation, Palo Alto, California

DESIGN OF TESTS FOR THE EFFECTS OF MASS FIRES ON SHELTER OCCUPANTS

By: William Lee
Helen C. Leong
Cordell Jee
and
M. Gayle Hershberger

Final Report
Contract No. NOO 228 66C0917
OCD Work Unit No. 1133B
T. O. No. 65-200 (64)

Prepared for:
Office of Civil Defense
Office of the Secretary of the Army
Washington, D. C. 20310

Through:
United States Naval Radiological
Defense Laboratory
San Francisco, California 94135

OCD Review Notice

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

NRDL-TRC-67

CONTENTS

INTRODUCTION

Mass Fires

Soon after the end of World War II there appeared an increasing number of disturbing accounts of the strange and unusually violent behavior of the mass fires resulting from incendiary and nuclear bombings of German and Japanese cities.[1]

These reports were largely put together from eyewitness accounts, newspaper stories at the time, city records, interviews with city officials, fire chiefs, etc., and naturally the data presented were very subjective and often incomplete.

However, even after allowing for some inconsistencies and conflicting details, a composite picture of possibly a new and heretofore unknown phenomenon of large scale fire behavior has gradually emerged which includes (1) the presence of extremely high wind velocities, often described as cyclonic, (2) strong whirlwind characteristics sucking air and dust into a central vortex or whirl, (3) large and heavy objects tossed about and sucked into these fire whirls and further adding to the plume of burning fuel, (4) very intense heat generated at the center of the disturbance, (5) large amounts of carbon monoxide and possibly other poisonous gases produced and carried to places relatively untouched by the fire itself, thereby causing unexpected deaths among pedestrians and shelter occupants.

Fire Storm Concept

At present, many scientists are of the opinion that under the right conditions, large scale mass fires or conflagrations may transform into this much more violent and hazardous phenomenon which they have come to refer to as "fire storm."

Since the possible existence of "fire storms" would have such far-reaching consequences on our present concepts of national defense and disaster planning, the Office of Civil Defense is conducting an extensive study of mass fire behavior and "fire storms." The possibility of "fire storms" poses many pressing questions which must be answered in a definitive manner. One of the most important questions is the effect of the fire storm concept on present shelter construction and shelter occupancy.

Operation Flambeau

Historically, shelters have been designed primarily for protection from fallout and blast.(2) Most urban shelters were located within large fire-resistant structures usually in basement locations. In rural areas, it was believed that individual fires would be small and isolated. Under these conditions, the added expense in design and construction of completely fire-proof shelters did not seem reasonable.(3)

The growing concern over mass fires and fire storms has required that many previous concepts of shelter design and management be critically re-evaluated. A broad program of basic and directed research was launched to study the entire mass fire problem. This included, in addition to the shelter hazard considerations, problems of operational analysis, command, training and fire control methods. The areas of basic research involved a review of weapons tactics, a survey of vulnerability and fire characteristics. It also took into consideration the physiological and psychological effects of fire on personnel both from the standpoint of management and public attitudes and response. Possible aspects of thermal attenuation, vulnerability reduction, detection and assessment were studied.

Several preliminary studies were conducted to explore the implications to shelter hazards and shelter protection. These studies were both information research type and laboratory studies on small scale fires and urban building burns. These studies furnished much valuable information; however, the results could not be assessed in proper relation to the overall shelter problem, since there were obviously large voids in the basic knowledge concerning mass fires and fire storm behaviors. There appeared to be many conflicting and confusing reports on the different aspects of fire storms. The descriptions offered by survivors were often exaggerated or distorted by personal opinion or reaction. If the fire appeared to be violent with high winds and intense heat, it was described as a fire storm. One person's conception of what constituted "high winds" and "intense heat " would not necessarily be the same as another's. Understandably, under the chaotic and turbulent situation which existed, very little objective data was recorded.

More definite and reliable information on the properties of mass fires and fire storms was obviously required before any significant progress could be made toward the stated objectives. In order to provide the missing

information, OCD undertook the task of initiating a program which they called "Operation Flambeau." Under this program, an attempt would be made to actually create and reproduce a "fire storm." This would provide the necessary tool to explore the fire storm hazard phenomenology with the ultimate goal of providing an effective safety and protection program.

The Forest Burns

A "novel" plan was proposed to simulate fire storms. The U.S. Forest Service offered to produce the "controlled and instrumented" large fire as a continuation of their existing mass fire and environment program. These were to be wildlands burns using the available vegetation as fuel and were to be conducted in safe, burned out areas[4]. Their fuel density and distribution were arranged to simulate typical suburban areas.

After several attempts with only limited success, the USFS was able, on June 14, 1966, to produce a mass fire with many of the hoped-for characteristics of the fire storm. High temperatures, strong winds and in-drafts were recorded and several distinct fire whirls were noted.

With the apparent success in the effort to reproduce a fire storm "on demand" the next step was to design and implement appropriate laboratory and field tests to use this tool, explore the implied hazards, and to develop appropriate protective mechanisms.

MASS FIRE LIFE HAZARD FACTORS

The various biological hazard factors affecting shelter occupants in a mass fire environment may be divided for the purpose of this discussion into four general categories.

1. Heat, both internal and external including that transmitted through the shelter walls and that which is brought in by the ventilation.

2. Common respiratory gases (O_2, CO_2, CO). Although CO is not normally considered a respiratory gas, it is included here because the high concentrations reported have a primary effect on normal respiration.

3. Smoke, dust and lesser known hazards associated with the mass fire itself, home or shelter construction, contents or equipment, countermeasures or fire fighting methods which may be employed.

4. Physiological, behavioral and other human engineering factors affecting shelter occupants which would have a significant influence on any of the above.

It should be pointed out that these categories are listed in order of decreasing existing knowledge concerning biological responses and, therefore, increasing difficulty of planning and devising appropriate and definitive test designs. They are not necessarily arranged, however, in order of importance from a hazard or protection standpoint.

MASS FIRE HEAT HAZARDS

Prior to a discussion of the biological responses to heat, it may be helpful to consider the nature of the heat source, the influences on the environment, and also the effects of the shelter. A brief consideration will, therefore, be given to some of the known or assumed characteristics of mass fires, their temperature effect on the environment surrounding the shelter and their influences on the internal shelter temperature. The possible elevation of the internal temperature due to the heat load produced by the occupants is also discussed.

Many factors are believed to contribute to the development and intensity of a mass fire. Some of these are the basic properties of the fuel (combustibility, ignition time, etc.), the fuel density, configuration of the terrain, wind velocities, and humidity[5].

The consensus is that urban and suburban residential areas are more vulnerable than commercial buildings since the latter usually have a self-contained fire control system. Residential areas, however, rely almost exclusively on public fire control facilities. Another reason for their vulnerability is that there is a high concentration of combustible materials confined to a relatively small area. The household "fuels" may be divided into three categories: (1) kindling fuel - objects with low ignition temperature, such as newspapers, magazines, drapes, etc., (2) heavy combustibles, which ignite after longer exposure to flame or kindling fuel, such as heavy furniture or articles having high moisture content, (3) fire resistant materials - objects which will not ignite after prolonged exposure, usually metallic items[6].

The topography of the fire area affects the rate and direction of fire spreading. For example, a fire will travel uphill faster because the fuel on the upslope of the fire is exposed to greater winds and heat. Wind facilitates the spread of fires by slanting the flames so that combustible materials in front of their path are easily ignited. The humidity of the ambient air is usually reflected in the moisture content of fuels and by this means affects their combustibility. The combination of all these and possibly other factors will determine the size and spread of mass fires.

Certain interim criteria have been proposed for predicting when a mass fire may turn into a "fire storm." These are based upon the fuel

density, fire density, surface wind, fire storm areas, and upon an unstable atmosphere[7].

The USFS workers, in their wildland burns, have been able to attain some measure of success in simulation of a large fire. They were able to arrive at high temperatures of about 2300°F with fire whirls and wind velocities of about 30 mph, which fulfill some of the requirements for mass fire standards.

It has been suggested that within 15 - 20 minutes after an atomic attack, the individual fires ignited by the blast will coalesce into a mass fire[8]. The severity of the mass fires has been related to the energy of the nuclear burst[9]. This lends support to the concept that mass fires are indeed a hazard to be reckoned with in the event of a nuclear disaster.

As dangerous as this environment is, survival may still be possible even within the fire areas. From reports of the Hamburg fires, it appears that passage through the streets is possible during the early phases of the mass fire. There is some indication, therefore, that escape is possible during this early buildup period. The time to peak temperature is apparently dependent upon the intensity of the fire. In low temperature experimental fires, aspirated air temperature sensors placed about 4.5 feet above ground level registered 20° above the ambient temperature of 45°F within 1.5 minutes and gradually dropped thereafter so that about 6 minutes after ignition it was only about 4 or 5° above the ambient temperature. In high intensity burns, of the order of 1400 to 2500°F, the peak temperatures were reached within 15 - 20 minutes after ignition. The peak time and/or the peak temperature varies with the location of measurement. The Camp Parks burn had sensors within a pile which registered its peak within 10 minutes with an accompanying thermocouple failure at 2400°F[10]. In a pile adjacent to it, although the time to peak was about the same, a maximum temperature around 300°F was registered. The temperature also varied directly as height above grade, i.e., lower temperatures were recorded on sensors located closer to grade level. This seems to support the report that it is possible to penetrate the fire for escape or rescue[11]. There is, however, the danger of the heat radiating from other surfaces such as from the piles or from buildings. Thermal radiation from the buildings causing ignition of clothing and inhalation of the heated air were some of the causes given for some German fatalities[1].

Heat radiating from piles made it impossible for unprotected people to walk in the area.

It appears that rubble temperatures persist for longer periods and this would influence the length of time the shelter could be occupied.

Temperature measurements made during the Camp Parks burn reflected the range that could be expected inside a shelter with various fuels burning outside the shelter. The fire from the rubble-free pile of fuel built up very rapidly and the thermocouples burned out within the first 10 minutes. In the rubble fuel pile, the fire temperature rose rapidly, but did not reach the height of the rubble-free pile. After about four hours, the rubble pile began to collapse around the vent leading from it and caused a second rise in temperature which remained for about two or more hours when the rubble settled below the vent entrance. A deep pile of heated rubble will expose the shelter to a slow heat rise(12).

The time required for an actual mass fire to become cool enough to approach may be as long as two days(13). The rubble in the Camp Parks burn remained hot long after the fire was essentially complete(10). When the burn area was cleared, five days after the fire, the rubble piles burst into flame when the fuel was exposed to the atmosphere by the bulldizer.

Temperatures as recorded with time inside open shelters in studies at the Nevada test sites were hot enough to produce third degree burns on some pigs. A few dogs, placed near the openings, had a total loss of hair and skin burns. This rise of temperature was due to the non-line-of-sight thermal burns resulting from high velocity hot dust-laden air traveling over the open shelters(14). Some data is available on human tolerance to heat pulses of short duration.

Reference has been made to the heat buildup in shelters if there is rubble piled up above it(15). There is some indication that with three feet of soil intervening, the heat does not penetrate for about 24 hours. This may be altered under different soil and soil type conditions. The heat transferred through the ventilating system can bring a net heat of 56,000 BTU/hour into the shelter, which is considered 100 times too high(10). Earlier standards of 85^{o}F effective temperature for upper limit survival may be too high(16).

Another area of heat buildup will result in overcrowded shelters from body heat[17]. Metabolic heat load to the shelter walls in hot ambient temperatures is a serious factor, especially if the outside temperature is high[18]. Metabolism and factors altering it are discussed under Biological Responses to Heat. Heat release rates of human bodies for the temperature ranges that may be expected in a shelter during summer months have been calculated[19]. Most of the ratings of shelters have been made from the standpoint of radiation and blast resistance. Shelters rated high in these areas may be inadequate against mass fires[20]. Mathematical shelter models have been verified by actual test with regard to shelter dry bulb temperature and effective temperature[19]. Heat transfer to shelters through different materials such as wood, concrete, soil and steel have been computed and the time calculated for temperature increase from 30° to 90°F[10].

From the foregoing discussions, it is apparent that although heat is a serious hazard, survival is possible at certain times, even within the fire zone. Heat affects the shelter interior whether it is from the external environment or from the metabolic heat load of its occupants. The hazard, however, can be minimized with proper shelter design.

BIOLOGICAL RESPONSE TO HEAT

When exposed to elevated temperature, the normal response of the body to heat is to compensate and adapt to the altered environment by changing its circulatory rate, heart rate, ventilation rate, vasomotor responses, i.e., shunting of blood to skin surfaces, and increased production of sweat. All these biological mechanisms work in the direction of attempting to throw off the heat gained by the body from the hot environment. There are upper limits at which the body can maintain this compensation in its adaptive effort. Many fundamental factors influence this limit such as sex, age, weight, and surface area, and are reflected in the metabolic rate of the subject. Other factors such as physical activity and emotional state vary this metabolic rate and thereby exert their influence on the body's tolerance to heat. "Acclimatization" or fitness training may increase the threshold tolerance. External factors, such as cooling systems and ventilation, aid in humidity and temperature control to keep the environmental temperature within tolerable limits. If, however, ventilation systems cool the internal environment too much, metabolism would increase. Knowledge of these factors will be useful in the consideration of habitability of shelter and performance efficiency. Of primary concern is man's ability to live and work in a hot environment. Biological testing is a means of exploring the possible ways of increasing his tolerance to heat and of protecting him from intense heat of mass fires.

It seems pertinent at this point to give a general discussion of metabolism, since this is the body's mechanism for energy transformation derived from stored or ingested foodstuffs, whose chief product is heat. Inherent or external factors which alter metabolic rate can vary the tolerance to any additional heat insult.

A discussion of basal metabolism is given to describe the baseline of metabolic heat factors. As early as the 1800's, the metabolic rates of various species of birds were investigated and it was found that the consumption of oxygen absorbed varied greatly with the weight of the bird. Sparrows had a metabolic rate (MR) 10 times greater than that of chickens. Since the temperature was the same for both, they reasoned that the smaller animal must have a greater surface area exposed to facilitate heat loss and that an increased respiratory rate probably helped also. Rubner elaborated on this

relationship of surface area to metabolism[21]. There is a slight variation of rate among species, but it is surprisingly close. A tabulation of various observers on basal rates for 31 species of birds and mammals falls within a range not too different from man. Eight species showed an MR between 30 - 40 calories per square meter per hour; eight were between 40 - 50 and six were between 50 - 60 calories per square meter per hour. The mouse and goat were below 30 (mouse: 22) while the elephant, turkey and swallow were above 60. These data are important in the selection of test animals. The basal metabolic rate is difficult to define as strictly related to size in various animals and birds; however, in man, the surface law relationship is accurately defined in terms of calories per square meter. DuBois[22] has devised a formula for a very close approximation of the body surface area:

$$\text{Area (square cm)} = \text{Weight (kg)}^{0.425} \times \text{H (cm)}^{0.725} \times 71.84$$

Kleiber[23] has shown that basal metabolic rate (BMR) in calories/hour is equal to $(\text{Weight in kg})^{0.75}$. For man, the BMR of 68 % of the population falls within 10 % of 40 calories per square meter per hour, 98 % are within ± 15 %. Since the center of metabolic activity is the center of the cell of the tissues of the body, a person with more fatty tissue would show slightly lower values; women show about 5 % lower values. The trained athlete shows about 5 % higher than the mean. The values also fall with age, presumably because there is less active tissue in older persons. DuBois[22] gives the following figures for "basal metabolic rate" (Table I). These figures represent the total energy exchange of resting and fasting individuals.

Table I

	Rate Cal/m /hr	
Age in years	Male	Female
5 - 10	52.0	49.0
10 - 15	47.0	43.0
20 - 30	40.0	36.0
40 - 60	37.0	34.0
70 - 80	35.5	33.0

In sleep, the metabolic rate usually falls below this defined basal rate.

Although this BMR is useful in detecting certain physiological disturbances, it is rather artificial to employ. Metabolism stated as calories produced per hour is a more useful tool. From the basal figure and a determination of actual rate one arrives at the efficiency of muscular activity and from this then can derive the amount of heat produced in activity. This combination provides a useful tool in investigation of problems dealing with high environmental temperatures. One can establish the limits of activity permitted without presenting hazard to physiological function.

Under ordinary circumstances, the metabolism of a 24 hour period with average muscular activity may be computed (Table II)[24]:

Table II

8 hrs sleep, 65 cal/hr	520	
6 hrs sitting at rest, 100 cal/hr	600	
2 hrs light exercise, 170 cal/hr	340	
8 hrs work, 240 cal/hr	1920	Total 3380 cal/24 hr

The daily extremes for various forms of normal activity can vary between 2000 - 5000 calories. For short periods exhaustive work can be performed. It has been observed that swimming, which requires about 500 calories per hour, can be endured for about four hours. For comparison, work requiring 1230 calories per hour can be performed for only about 20 minutes. Tripling this value can be endured for only 30 seconds before exhaustion occurs. These values are upper limits. From these values, tolerance in relation to time of endurance, one can relate amount of activity tolerated in the hot environment and the tolerance time.

There is an "ambient critical temperature" for man. This is the temperature at which no influence is exerted on the body's heat production. If the ambient temperature is sufficient to increase the body temperature by a few tenths of a degree Centigrade, the metabolic rate will increase. This should be taken into account when biological controls are to be established in studying other hazards. This affects shelter systems in that this increase will increase the O_2 requirement in the ventilating system and will also add to the internal heat load[18]. It affects the occupant's nutritional needs and indirectly his performance ability. Gagge, Winslow and Henderson found

that this range is from 20 - 24.9°C[25]; Lefevre[26] set it between 22 - 27°C, and DuBois[27] sets it at 27.4°C for the upper limit. Above or below this critical range, there is an increased metabolism.

The regulation of heat gain through metabolism is dependent upon many mechanisms. One of the more important of these is muscular activity, whether it be exercise or muscle tone. Since muscle forms approximately one-third of the body mass, the heat produced per unit weight contributes a large proportion of the total heat produced. In trying to maintain the body temperature of the shelter occupant, therefore, the amount of physical exertion required of the individual should be considered.

Since metabolism is an important factor in heat production and, therefore, body temperature, anything that increases it will of necessity add to the stress. The emotional state of a person influences his metabolic rate. With emotional anxiety or fear, the epinephrine level is elevated and this increases the metabolism of the body with a resultant increase in heat production. The psychological response to mass fire conditions, therefore, also affects thermal tolerance. This psychological factor along with exercise or effective work performance are factors where training or some educational program would be an advantage.

Metabolism involves the utilization of materials within the body with the production of heat. Various foods produce different amounts of heat. This may influence the types of food that should be stored in shelters.

While man's heat production process is only through metabolism, influenced by many factors, the heat loss is effected through radiation (60 %), convection (15 %) and evaporation (25 %). To facilitate bringing heat to the surface of his body so that it can be transferred to the environment, he increases his respiratory rate which enhances insensible water loss, his heart rate increases so that more blood is circulated to the surface vessels which are dilated, and finally, his sweat production is increased. Sweat production plays a major role in heat tolerance. Man can withstand a dry environmental temperature of up to 127°C (260°F) for eight minutes if he evaporates enough sweat[27]. He must, however, drink an equivalent amount of water to replace this water loss to prevent hemoconcentration and accompanying water imbalance.

Replacement of this water loss greatly aids heat tolerance with a resultant greater work performance. It was shown that men marching in a hot

environment showed a lower increase in rectal temperature when water was replaced at hourly intervals than those who had no water or water given ad libitum. With an exposure duration of six hours, individuals with water had rectal temperatures of 38°C or only 0.5°C elevation, whereas subjects with no water had an elevation of 1°C and showed signs of heat stress and could not perform effectively beyond 5.5 hours[28]. The body tolerance of increased temperature is very sensitive and therefore a rise of 1 or 2 degrees is significant. It is interesting to note that hourly ad libitum water intake is not sufficient to cover the sweat loss; in these cases, the rectal temperature rose to about 39°C, also. A sweating rate of one liter per hour can be maintained for many hours if water is replaced, but if the rate is between 1.3 to 1.8 liters per hour, it cannot be sustained for more than six hours[29]. Sweat production varies with individuals. The production of sweat is not in itself the mechanism for heat loss, but rather the evaporation of the moisture. This poses a problem of humidity control in a shelter. In a moisture-saturated atmosphere a temperature of 50°C cannot be tolerated for more than a few minutes because in spite of adequate sweat production, it is not vaporized and therefore no heat is lost.

The type and amount of clothing worn by the shelter occupant could help him in his feeling of well being as well as maintaining temperature. However, it is helpful only up to a certain point, since it affords a greater evaporative surface only until it is saturated; then it builds a high vapor tension environment around the skin evaporative surface and the usefulness of clothing is negative. Of course, light colored clothing in its reflective ability protects from radiant sources of heat and is useful in this way.

Evaporation is relatively constant in a clothed, resting subject until an air-wall temperature rises above 27°C (80°F), then there is an increase up to as much as 65 gm/m^2/hour at 32°C ambient temperature[30]. The skin temperature rises from 33°C to 36°C during this time, but the rectal temperature remains constant at 37°C due to various biological adaptations. Therefore, although the rectal temperature is an indication of true body temperature, it does not show responsive body change. As the skin temperature increases, the sweat production can increase as much as four times, from 100 - 400 gms/hour[31]. Humidity, of necessity, influences the evaporative water loss since the environment-body surface temperature gradient is decreased with increased

vapor tension in the air. Air movement in a shelter aids evaporation but also increases the humidity of the environment. The relationships of vapor pressure and air-wall temperature to comfort and various thermal limits have been investigated[32]. This data would be helpful in the design of shelters. An optimal environmental temperature for thermal regulatory balance with no stress and a sensation of well being seems to be at 20°C with 50 - 60 % humidity. Mild exercise is tolerable and advisable for most. The amount depends on physical fitness or work done by the shelter occupants.

In tests with subjects wearing clothes with insulation value of one clo in an environment of three different severe transient heat exposures of 400°F (201°C), 300°F (150°C) and 250°F (121°C), their heart rates increased with the accompanying skin temperature increase. The skin temperature rose and came close to the pain limit. The pain threshold is 45°C and pain is intolerable at 46°C. These severe exposures also come close to the heat storage limit. If the blood supply to the surface of the skin is large enough, it can carry the heat away and store it within the body; however, at these severe exposures the limit is attained. Duration of tolerance to 400°F is about eight minutes; at this level, the heart rate increases by 60 beats per minute. Exposure to 300°F was endured for about 15 minutes and increased the heart rate by 40 beats per minute. At the lowest temperature (250°F), the tolerance time was slightly more than at 300°F and the change in heart rate was 45 beats per minute, which is about the same response for 250°F as for the 300°F exposure. The mean skin temperature rose to about 44°C[33,34].

Wall temperatures were increased in 100 F degree per minute steps up to 500°F in a series of experiments to determine the effectiveness of different types of clothing to tolerance time. Nude subjects tolerated 410°F for five minutes, with light underwear on they endured 430°F for six minutes; in summer flight clothing, they tolerated about 480°F for about 6.5 minutes. In heavy winter flight clothing, they were able to tolerate 520°F for seven minutes. With heavy aluminized coveralls, they were able to extend the time to 10 minutes and by ventilating these coveralls the time of tolerance went beyond 20 minutes. Adding ventilation of air at 85°F allowed all the exposures to be extended beyond 20 minutes[35].

Thermal radiation upon skin areas was tested and the time for pain sensation recorded. It was shown that sources from simulated thermal flash of nuclear weapons (100 - 220 BTU/ft^2 min) upon the forehead or forearm

exhibited a pain reaction within one second. Below these levels, at about 25 BTU/ft^2 min, the main threshold was reached within 10 seconds. There was no distinguishable pain response to lower doses, which indicates that below 25 BTU/ft^2 min the blood supply to the skin was apparently able to carry the heat away for storage. The heat transfer coefficient which is dependent upon air density, air velocity, surface area and shape also exerts an influence on how hot the ambient temperature can be before the pain threshold is reached[36].

COMMON RESPIRATORY GASES (O_2, CO_2 and CO)

Discussion in this section is limited to O_2, CO_2 and CO. Although carbon monoxide (CO) is not actually a normal participant in the human respiratory cycle, it is included here since it has been reported that large concentrations were present during mass fires and many deaths were attributed to CO poisoning which exerts a primary effect on the respiratory process.

Oxygen (O_2)

There are indications that during mass fires oxygen levels decrease as CO_2 and CO levels are increased. A decrease of O_2 from the normal ambient level of 21 % was observed in many fires(12). Gas samples taken from test burns have shown a drop to 5 % at a height of 20 feet(5) and even to 2 % at eight feet or less(10). This was usually at peak temperature times and sometimes at highest CO levels. In house burns, O_2 depletion was greatest inside the structure compared to samples taken on the outside between houses(10) Here again, it was associated with peak temperatures which, as expected, developed later than in other locations.

The concentration of O_2 varies at different levels in the fire itself. It appears that C_2 levels are lower at one foot above ground level than at 20 feet(5). These data suggest that in the fire environment, there is an O_2 reduction which seems to be associated with peak temperatures. This deficit appears to be in a range which would be a definite hazard from the biological standpoint.

The amount of oxygen available to the tissue of the body depends on the relationship between the barometric pressure and the oxygen content of the inhaled atmosphere. Under mass fire conditions, there may be barometric changes which compound O_2 depletion created by the combustion of materials.

Atmospheric air contains 21 % O_2 by volume, which is equivalent to a 95 % saturation with O_2 of the blood as it leaves the alveoli in the lungs. The saturation of the blood is dependent upon the pressure of O_2 presented to it. Therefore, it would be necessary to increase the per cent concentration of O_2 if there is a barometric pressure decrease in order to maintain 95 % saturation of the blood. As this blood travels through the body, various organs pick up the oxygen by diffusion due to O_2 pressure differences between

themselves and the blood. In this manner, the arterial blood becomes "reduced" or less saturated and becomes venous blood and returns to the lungs where it is again oxygenated.

Since the body's only source of O_2 is that from the environment, a constant supply line must be maintained between the blood and the lungs which are exposed to the environment. O_2 is essential for the maintenance of all biological processes. Some organs require less whereas another, such as the brain, requires almost 20 % of the total available O_2 . Muscle can function temporarily without O_2 until its reserve mechanisms fail.

The normal unimpaired performance by an individual is greatly affected when the concentration of O_2 drops much below that of normal air. At 10 %, there are physiological signs of distress (anoxia), i.e., dizziness, shortness of breath, rapid respiratory rates and increased heart rate. These are signs of the lack of O_2 to the brain and the body's effort to compensate by increasing the blood circulation so that more O_2 is presented to the tissues.

At 7 %, stupor sets in and 5 % is the minimal life sustaining level. At 2 - 3 %, death is inevitable within one minute[37]. There is also a toxic effect produced by prolonged exposure to high O_2 levels. The mechanism for this has not been clearly defined. Uncontrolled availability of O_2 during emergencies may not be the answer in all cases[38]. There are reports that people have penetrated the mass fire area along the trenches and that O_2 levels are tolerable between burning fires[76]. This may be due to the inrushing winds from the perimeter. After the last USFS test fire, the aisles had a clean-swept appearance which seemed to indicate some wind activity along these corridors[78]. Nevertheless, hazardous and, in some cases, highly toxic levels of O_2 deficit have been registered.

Carbon Dioxide (CO_2)

CO_2 is the gas normally produced in complete combustion processes. In experimental fires, high levels of CO_2 are usually accompanied by decreased O_2 concentrations. In addition, there may be appreciable differences of peak CO_2 levels and peak temperature times, depending upon where the gas was sampled. In rubble-free piles, the CO_2 reached 7.7 % at about six minutes and then rapidly fell to about 1 % within 10 minutes. Above rubble piles, the gas reached the same upper limit at 14 minutes; dropped after 30, and then

rose to a second peak of 6 - 8 % and maintained this for about two hours[10]. In building burns, 11 - 13 % CO_2 was observed[12]. Analysis of bottled gas samples from probings of piles and from within hot coals 20 hours after ignition showed that the CO_2 was 8 %[10].

There are many extraneous sources of CO_2 production which could add to the existing levels of CO_2 produced by the fires. The ratio of the CO_2 produced and the amount of O_2 consumed within a shelter by the occupant is a serious consideration in evaluation of ventilation systems. In a submarine experiment, it has been demonstrated that under "typical" conditions the expired air of its occupants could contribute an additional 1 % CO_2 or more to the enclosed atmosphere. This may be significant in a sealed area when added to other possible sources[39].

CO_2 may also be introduced into the shelter by the use of conventional fire extinguishers. In the pioneer days of aviation, several deaths resulted from the CO_2 released by extinguishers located inside the plane[40]. In the shelter, other sources such as smoking, cooking, operation of machinery may contribute to the mass fire CO_2.

The amount of CO_2 inhaled plays a major role in controlling respiratory and cardiovascular systems. The ventilation rate is increased to about 75 l/min, which is an elevation of approximately 15 times normal rate, when the concentration of CO_2 is increased to approximately 10 % in the inspired air. The respiratory center is more sensitive to percentage CO_2 increase than O_2 deficit. By decreasing O_2 to 10 % in the inspired air, the rate is only doubled[41]. Extremely high concentration of CO_2 acts in a reverse manner and reduces respiratory volume due to an anesthetic effect.

The hazards of increased CO_2 inhalation are often associated with O_2 depletion, but increased inhalation of CO_2 may be harmful even when O_2 concentrations are normal.

Breathing becomes deeper and tidal volume increases when the amount of CO_2 inhaled is above 2.0 % of total volume inhaled. Considerable discomfort with quickened and deeper breathing will occur when the CO_2 level rises above 4.0 % in air. Nausea may occur with extremely labored breathing with concentration of CO_2 of 5 %. The human tolerance limit is usually considered to be between 7 - 9 %. Unconsciousness will occur after approximately 10 minutes when the CO_2 level rises above 10 %. If the CO_2 concentration reaches around

18 %, there will be extreme discomfort, mental dullness and throbbing in the head. Partial spasms and respiratory inhibition are produced when the CO_2 level reaches 20 %. Death will occur due to a blood pressure coma when man is exposed to CO_2 concentrations between 25 - 30 %. Very high concentrations of CO_2 (64.6 % CO_2 and 8.6 % O_2) were irrespirable because of spasms of the glottis and immediate inhibition of respiration.

The average of normal atmospheric CO_2 in 1962 was about 300 ppm (0.03 %) but the rate of increase is approximately 1 ppm/yr[79]. Whether this increase will eventually acclimatize man to better tolerate increased CO_2 concentrations or whether it will weaken his tolerance is not established. The biological responses to sudden and acute exposures of CO_2 are more immediate and severe than those of prolonged exposure to gradual increases of CO_2 levels. Experimental subjects were placed in a closed space and the CO_2 concentration was allowed to increase gradually up to 5.6 - 5.8 % in an eight hour period. Breathing became labored between 4.7 to 5.2 %. All subjects showed fatigue, chilliness, subjective depressions, and headache. Two subjects were allowed to enter the chamber when the CO_2 level had reached 5.5 to 5.8 %. They were thus subjected to an acute exposure and became so dyspneic that it was impossible to make physiological observations[42].

It has been suggested that 3 % CO_2 atmosphere can be tolerated by humans. Work has been done at Brooks School of Aerospace Medicine where men have lived in 3 % CO_2 for five days without ill effects. However, other studies have demonstrated that prolonged exposure of 40 days will cause biochemical changes as well as mild physiological strain in concentrations around 3 %.

Carbon Monoxide (CO)

In various experimental fires, large and small, the variation of CO concentration has been great. It varies from 6 % to almost none[10]. This variation may be due to many reasons. The location of sampling appears to be a strong factor. When the gas samples were taken 20 feet above the fire, the CO concentrations were considerably lower than that found at 12 inches. Lower concentrations were obtained near the edge of the fire and no significant amounts were present in the "streets" of the test fires. Rubble-free piles released 1.5 % CO about six minutes after ignition, whereas slowly burning or

smoldering rubble produced 6 - 7 % CO for three to four hours. Why does the location make a difference? It may involve two factors - the incompleteness of combustion and/or the "diluting" effect of the whirlwinds or wind activity. The fact that the area of smoldering rubble usually has a higher atmosphere of CO may support the former. In a rubble pile, there is an observed decrease of O_2 perhaps indicating incomplete combustion and there is absence of any wind activity. In the Richmond Burn #2, at about 20 minutes the temperature of the vent inside the building was about 2600°F (peak temperature) while CO was approaching its peak of approximately 1 % and the O_2 was decreased to about 5 %. This occurred as the building began to collapse into a pile of rubble and the "roaring fire began to die down"[5]. The data from other fires (Camp Parks and Briones) conducted by the same investigators indicated similar results. The periphery of the fire showed very low CO and is the point where dilution with the inrushing winds may occur. About 0.3 % CO levels were obtained at the last USFS 40 acre fire. Although this appears relatively low, it would cause headaches, dizziness and nausea with a 10 minute exposure and collapse and danger of death at about 50 minutes. Frontal headaches are experienced in 2 - 3 hour exposure to 0.02 % CO. The current Threshold Limit Value (TLV) for eight hours a day exposure is 0.01 % CO (100 ppm)[67].

In experimental mass fires, limited types of fuel have been used. In an actual urban mass fire situation, incomplete combustion of other organic material may result in higher CO levels. For example, under normal conditions blast furnace stack gas contains 28.0 %, and arc furnaces used in melting aluminum produced 32 % CO. The experimental burning of various combinations of chemical components to produce smokes have indicated up to 1 % CO in an enclosed area[43].

Within a sealed shelter, smoking by the occupants or burning or cooking can add to the hazard. Since rubble contributes to toxic levels for hours later, it is advisable to consider rubble removal away from the shelter area or provisions made to have a special source of respirable air.

Many reports have been published on the effect of CO poisoning in man. Haldane, Barcroft, Henderson and others[44,45,46] have done extensive work in establishing the effect of CO on the hemoglobin of the red cell. In the presence of CO, the hemoglobin (Hb) in the red blood cell, which ordinarily carries the oxygen in combination as oxyhemoglobin (HbO) until it is released

to the tissue combines instead to form carboxyhemoglobin (HbCO). In man, the affinity of CO for Hb is 210 - 300 times greater than for oxygen. This affinity number varies with species. Because of this high affinity, a very minute amount of CO in the air can cause a considerable decrease in O_2 carrying power. Roughton and Darling[47] have also shown that the resultant HbCO inhibits the dissociation of the oxyhemoglobin so that in effect the Hb is hanging onto the oxygen and not releasing it to the tissues as readily. The reaction of CO and Hb is reversible and in the presence of air or pure O_2, the CO is eliminated with no adverse effect to the Hb O_2 transport.

Carboxyhemoglobin (HbCO) gives the blood a characteristic bright cherry red color. In cases of extreme poisoning resulting in death, the body shows red blotching in contrast to the cyanotic appearance of usual anoxia. From reports on the Hamburg fires, there were victims who exhibited a bright red coloring but no autopsy was made, so the cause of death was not given[48]. Although other factors could bring about this blush, CO must be considered.

A general rule of thumb constant for each degree of physiologic effect was presented by Henderson and co-workers[49] where CO concentration is given as CO in air in parts per 10 thousand multiplied by the exposure time in hours.

Table III

Time x concentration =	3,	no perceptible effect
	6,	just perceptible effect
	9,	headache and nausea
	10,	dangerous

Haldane[50] sets the figure at 100 ppm (parts per million) (0.01 %) for appearance of symptoms. The American Standards Association has adopted this as the maximum allowable concentration for a daily exposure of not over eight hours. For exposure of one hour, they have accepted up to 400 ppm (0.04 %). The Bureau of Medicine and Surgery has recommended Interim Threshold Limits for one hour exposures (not repeated short term exposures) be set at 0.02 %[39]. In man, a 100 ppm (0.01 % in air) concentration leads to a blood saturation of 16 %. It has been demonstrated that increased temperature and activity decreases the tolerance to CO. Age and sex also influence CO tolerance. Women survive heavy exposures better than men; this is probably due to the fact that men breathe more deeply. In animal experi-

ments, it has been observed that young rats and pregnant rats succumb more rapidly than old and/or non-pregnant rats Newborn and those recovering from major surgery are especially sensitive.

In some dog studies, Lewey and his associates[51] have shown that 100 ppm (0.01 %) produces muscle fiber degeneration, necroses, altered EKG picture, and certain neurologic signs although the condition of the dogs generally appeared excellent. They have not transferred these findings to humans, but they do find changes in dogs at what are considered safe levels for man.

It must be noted here that given standards should serve only as a general guide for toxicity and effects. Various factors explained and unexplained may alter CO tolerance. It is generally recognized that a 66 % saturation level of carboxyhemoglobin is lethal[52]. The per cent Hb saturation at various CO volume per cents is a key to alterations in tolerance levels. 0.1 % concentration causes a CO saturation of the blood up to 50 % in about 15 minutes. This reaches 80 % in about 20 minutes, but if the man is exerting himself, the same lethal saturation can be reached within five minutes. However, the degree of saturation may not be fatal if immediate treatment is provided.

Many factors can summate with the CO effects and therefore produce at lower levels a picture usually associated with higher levels. In anemia where there is a reduction in the total number of red blood cells, a 25 % anemia coupled with 25 % HbCO could give anoxic effects equal to 50 % HbCO. Impairment of ventilation, circulation, and gaseous exchange systems, all can contribute to increased vulnerability to CO.

Carbon monoxide poisoning can be divided into three categories: acute asphyxia, acute asphyxia with delayed symptoms, and "chronic" poisoning. All three conditions may be encountered in the event of mass fires.

The first of these is the acute asphyxia. This occurs where there is sudden gassing or very short exposure to high concentrations. Recovery takes place within a few hours, at most 24 - 48 hours without residual signs or symptoms if immediate treatment with air or pure oxygen is given.

The second, acute asphyxia with delayed effects, occurs when the dose is sub-lethal but of longer exposure time. There may be total recovery with no damage or the damage may become apparent in 2 - 3 days, or, in some cases, even up to several weeks after the initial coma. This damage may be

of short duration or may be permanent. Central impairment is most pronounced since the central nervous system suffers most from anoxia. The picture is varied and runs the gamut from emotional instability to the extreme of mental derangement. There may be apathy, disinterest or highly volatile emotional states and hallucinations. Physical symptoms may include convulsive seizures, twitching or choreaform movements. Loss of memory and lack of judgment are considered definite symptoms of poisoning, both while the victim is under its influence and during recovery. The elimination of CO from the blood does not always stop the degenerative processes set up in the central nervous system. These degenerative processes may lead to progressive symptoms of mental impairment with motor and sensory involvement. In rare cases of severe asphyxia with incomplete recovery, mental aberrations persist even after motor control is recovered.

Visual impairment resulting from congestion of the retinal veins and hyperemia of the disk is the earliest and most constant ocular sign. Blindness is rare. Halperin and his associates(53) found an increased sensitivity to light with as low as 3 % HbCO saturation. They attributed this to a tissue absorption of about a third of the CO administered. Visual impairment responded to pure O_2 therapy, but did not do as well with air. They postulated that there may be visual substance, as yet unidentified, which shows the same affinity for CO as Hb.

In humans, there does not seem to be a consistency of heart damage and usually observed damage is probably due to a previous cardiac history(54). Stearns, Drinker and Shaughnessy(55) feel that the EKG abnormalities are transitory. However, it should not be implied that there can be no heart damage. If there is a cardiac response, it usually occurs immediately following exposure.

There is an increased glycosuria which may last for a few days. This is probably an adrenal response to anoxia. Rarely is there kidney malfunction, and the albuminuria that appears initially usually disappears after recovery.

The final hazard category is that of chronic poisoning. This has been questioned by some workers because carbon monoxide is not accumulated in the body as in the case of lead or arsenic. The classification of chronic poisoning is perhaps more reasonably restated as a series of acute poisonings

with recovery in between exposures. Beck and his associates are the primary proponents of chronic poisoning They reported elevated red blood cell counts in steel workers and attributed this to protracted exposure to small amounts of CO. Many have refuted this idea of chronic poisoning on the premise that CO is so rapidly eliminated from the body there could be no accumulation. Also, most of the damage occurs from anoxemia and since low concentrations cannot produce this state, they reject this idea. In a careful study, Lindgren(56) examined workers who occupationally were exposed to levels equal to that reported for chronic victims and found that although there were complaints of headaches, these did not exceed those of the control group and no other symptoms were observed. The Public Health Service(57) studying men working in the Holland Tunnel for years, found no sign of health impairment suggesting occupational disease. This chronic poisoning hypothesis is accepted by Lewey as a clinical entity. He explains it as being due not to the accumulation of carbon monoxide, but rather to a slow accumulation of the effects of the damage done day by day by a moderate degree of anoxemia. Lewey and Drabkins(51) found daily levels of 20 % HbCO in their dogs, but no HbCO could be detected before each day's exposure. At autopsy some months later, anoxic degenerative changes were found in the cortex and white matter of the cerebrum and brain stem similar to that in acute poisoning but smaller and more scattered and less intense. It is possible, therefore, that although daily blood CO saturation levels may seem normal, there may be internal damage from these low exposures.

In mild cases of CO gassing, such as ordinarily seen in industry, there are no objective tests which can be measured clinically and ascribed solely to CO except for the measurement of HbCO saturation in a blood sample. This must be made before the victim has been exposed to fresh air or oxygen. It had been supposed that CO is eliminated rapidly; however, in recent studies Sayers and Yant have found that without oxygen treatment, it is not as rapid as presumed. They found that it took 9 - 10 hours to lower the blood saturation from 35 % to 5 %; Farmer and Crittendon(58) found that steel workers who had a 7 % saturation came back to work 16 hours later with a 2 % saturation of HbCO. To insure a rapid elimination of CO so that further damage is not incurred, oxygen administration should be started immediately after exposure.

SMOKES, DUSTS, OTHER LESSER KNOWN HAZARDS

Particulates

Some studies and observations which have been made on the deleterious effects of air-borne contaminants indicate the need for closer scrutiny of particulates as a potential health hazard in the mass fire environment. One may assume that in a vigorously burning area, all types of smokes and particles that would be emitted to the atmosphere would be at least irritating to the respiratory system, if not highly injurious.

Tebbins describes particulate matter as small particles which are not homogeneous in concentration or composition, which can be washed out of air or tends to settle out. Examples of these are smoke, dust, ashes, etc.[59] A suspension of small particles, liquid or solid, in a gas phase is termed an aerosol. In Great Britain, the preferred terminology for the suspended component of an aerosol is particulates. The commonly accepted range for aerosols is from 0.01 - 10 microns. If the particles are liquid they are spherical and if they are solid they approximate spheres in their behavior. They may be of uniform size or of varied size, heterogeneous aerosols or homogeneous aerosols [60].

Aerosol is a generic term for smokes, fogs, dusts and also hazes. The size and whether the suspended particles are solid or liquid are factors which determine the specific term to be used. If the solid particles are of the order of 0.01 - 1 micron, they are referred to as smoke and are commonly associated with the carbon and ash particles arising from fires. Smoke is often composed of fine solid particles which have coagulated to form chains or filaments of larger particles. Dust is comprised of larger particles of any material blown up by wind or air movement. There is an overlapping of types of aerosols and in the case of dust this is evident. For example, dust particles may range from 0.01 micron or less such as encountered in haze, to sandstorms which have particles beyond the normal range of aerosols. Fog is usually considered as water droplets and natural-occurring fog is of relatively large particle size, 10 - 50 microns. However, tobacco smoke is very hygroscopic but is not generally defined as a fog. Artificial fogs include droplets of any liquid such as water, oil, or acid [60].

Under ordinary conditions, the stability of an aerosol is chiefly

influenced by Brownian movement and gravity settling. Brownian motion causes the particles to collide with each other to form spherical aggregates or filaments or in the case of liquids to coalesce and form larger droplets. The efficiency of formation of larger size upon collision appears to be close to 100 %[61]. The adhesive forces tend to be greater than any force of separation even when electrical forces are applied. Under the force of gravity the particles settle on any horizontal surface, the rate of settling being proportional to the cross sectional area.

When the particles adhere to other than horizontal planes, then either thermal, electrical or acoustical forces are acting. Thermal gradients force the particles toward objects colder than its surrounding medium. Centrifugal forces are employed in cascade impactors and impingers which separate various particle sizes. Supersonic frequencies and high intensity sound waves cause rapid coagulation of smoke particles for easier entrapment. Evaporation, condensation and convection currents influence the stability of the aerosols through their effect on the particle size and on the density of the aerosol, which in turn affects the rapidity with which the particles settle out. Examples of this are dusts from steam pipes which adhere to the adjacent cold walls or ceiling. Static electricity can produce a precipitation of dust. Sirens of certain intensities have been employed to dissipate fog. Explosions can precipitate rain and dust. These factors can be significant in mass fires where explosions would be common. Because of the thermal gradients between fire environment and shelter air intake systems, there may be an unwanted attraction of particulates. On the other hand, this factor can be advantageous in trapping and eliminating the contaminants before they reach the shelter interior. Dilute aerosols of very fine particles such as volcanic dust or that produced with a nuclear detonation can stay suspended at high altitudes and settle at a very slow rate. This may become a longer term hazard of possible significance. The biological hazards of smoke, the nature of the smoke and duration of contamination are subjects for further investigation.

Natural circumstances which lead to dissipation or spread of smokes have been studied. The initial tendency for smoke to rise is due to the heat expansion of its components and is governed by the molecular weight

of the gases. Heavy smoke contains gases of higher molecular weight than its surrounding medium such as air. Smoke containing high percentage of CO_2 will tend to sink. CO_2 as it rises loses its heat by radiation and on cooling will sink since it is heavier than the air which has a high percentage of N_2. Soot will absorb heat from the sun and its surroundings and therefore will not cool as rapidly.

Meteorological and topographical factors also influence the stability, travel distance and the direction of a smoke plume. In general, wind direction and velocity will determine the direction and the rapidity with which the smoke will travel. The thermal stability of the atmosphere will govern its rise. If the thermal gradient between earth surface and the air layer above it is great, an instability of a smoke cloud is effected, which leads to a turbulence and possible dissipation of the smoke. Topographical factors may enhance or offer barriers to the spread of smoke.

In cases of fire whirls or similar turbulence, particulates of larger size may be churned about and kept in motion, so that at greater distances away from ground zero or for longer periods, particles which ordinarily would settle from gravity in the immediate vicinity could present a problem to be considered. In the Hamburg fires, it was reported that great amounts of smoke and dust moved along the pavement [59].

In experimental wildland burns, dense black smoke was observed in the early stages. This smoke then became grey with time. The black smoke may be less hazardous than the lighter colored smoke which persisted in the later stages. Black smoke to the casual observer appears to indicate the presence of a large amount of particulate material. However, combustion process studies have demonstrated that this was usually not the case. For example, the dense plumes of black smoke produced by the burning of hydrocarbons contained 99 % innocuous gases (O_2, N_2, CO_2) and less than 1 % by weight or volume of particulates, liquid aerosols or pollutant gases. The blackness is evidently due to the light scattering properties of the materials in the size range of 0.3 to 0.5 microns [62].

On the other hand, large particles may appear invisible and be discharging more contaminants into the air. With high burning rates, where combustion is incomplete, up to 50% of the fuel may be passed out unburned as exhaust. Smoke screens often employed as countermeasure mechanisms,

besides their properties of irritation and discomfort may be a source of considerable health hazard. Studies on rats, mice and guinea pigs have indicated that deaths from smokes increased as the number of test units burned per unit area of exposure chamber increased. Of the smokes generated by pyotechnic items, it appeared that there was a decreasing order of toxicity from yellow, red, green and black. Black smokes were least toxic [43].

Visual appearance is not indicative of the contaminants and therefore it may possibly be more appropriate to investigate the composition of the smoke generated in order to properly assess its hazard on the living organism.

In addition to the possibility of radioactive contaminants adhering to the particulate surface, many factors enter into the question of how hazardous particulates are to man. Among these are: the physical and chemical properties of the inhaled particulate material; the amount inhaled which is governed by the concentration and time of exposure, and physiological responses of respiratory rate and minute volume. Once inhaled, the deposition site and whether the body is able to eliminate or absorb the material without injurious effects are important factors.

Some biological data are available which may be useful in evaluating air-borne contaminants under mass fire conditions. These could provide useful guidelines in assessing efficacy of protective measures. Particle size and respiratory rate influence the ultimate deposition site. It has been estimated that 10 - 30 micron particles are deposited in the terminal bronchioles of the lungs, while larger particles are distributed in upper tracts of the trachea, larynx, pharynx, and the nasal passages and sinuses [63]. There is a marked variability in the amount of inhaled material deposited, depending upon the respiratory rate as well as the particle size. Percentage deposition of particles of 1 micron in diameter may vary from 20 - 80%, depending upon the rate. To produce a similar range variation, the particle size may be changed as much as ten fold, from 0.5 - 5 microns. Minimum alveolar retention at 0.25 micron size was about 40% in four dust studies [64]. Air pollution investigations have shown that 5 - 6 micron particles are deposited in the mid-respiratory tract and particles of 1 or less reach the alveoli. However, 0.5 - 0.01 micron particles settle out less rapidly and the amount of retention may be decreased. Less than 0.1 micron particles tend to move in and out of the respiratory tract.

Inert dusts of low solubility and toxicity can be hazardous merely from the physical occlusion of bronchioles which can produce asphyxia.

In a projected calculation of dust inhalation sufficient to produce suffocation in man, it was determined that with a dust density of 1.5 gm/cc, a lung retention of 50 % by weight of material inhaled, and a ventilation rate of 10 liters per minute (resting), a resultant dust concentration of 50 gm/m^3 produced suffocation in 180 minutes. Doubling the dust concentration produced the effect in 90 minutes. When the ventilation rate was increased to 90 liters per minute, the time was reduced to 20 and 10 minutes respectively.

Desaga(65) substantiated these projections in his experiments. In his experiment on a dog, the 25 gm/m^3 concentration appears to be the marginal concentration and perhaps this is true for man. The dust sediment was found only in the upper one-third of the trachea. Some dust was observed in the alveoli. The ciliary action of the respiratory tract apparently is able to eliminate the dust up to the marginal concentration. It is known that cigarette smoking inhibits ciliary activity; the smoker's marginal concentration conceivably would be lower.

The relationship of coal dust and emphysema gives impetus to further studies on the relationship between dusts resulting from mass fires and loss of elasticity in the lungs. The possibility of chemical interaction between various types of dusts and smokes and the elasticity of the lungs should not be overlooked. On the other hand, it may be dangerous only because it offers mechanical irritation and blockage.

In the internal shelter environment, dust may be generated from external effects on its components. In some work on blast effects on shelters, particulate material falling from the walls and ceilings was collected by various means and analyzed for particle size. A high percentage of these particles was found to be less than 10 micron diameter. It was suggested that particles of this size may penetrate deeply into the respiratory tract and may be deposited in the alveoli where they could interfere with normal gaseous exchange with the blood(14). There have been instances reported that dusts from shelter were lethal to its occupant(65).

Other Gases

There are several gases predicted to be produced by a mass fire, but the detection of these gases and their concentration has not been established. It is not known if the present conditions of Flambeau will produce all the gases predicted to exist if an average subdivision should burn, because the fuel differs considerably. The average subdivision will have large amounts of: rubber (i.e., backing for carpets, stuffing for furniture, automobile tires, etc.); petroleum products (i.e., gasoline in automobiles, power lawn mowers, asphalt, tar, paint thinner, etc.); synthetic material (i.e., records, carpets, draperies, etc.). The toxicity of substances produced by the combustion of these products is not known at this time, and extensive work is needed in this field.

Ozone. Exposure of 1-1/4 ppm for one hour will result in an increased residual volume of the lung and a decrease in the breathing capacity. Higher levels tend to produce pulmonary edema, hemorrhage, and interference with the diffusion of gases from the lung alveoli to the blood. Precipitators, home air purifiers and other electrical machinery may be a source of this gas[66].

SO_2. It is generally agreed that in the range between 1 and 5 ppm, most people will show a physiological effect. The primary effect of low concentrations of SO_2 seems to be a blocking of the air passages. A suspected source of this gas may be the oxidation of sanitary tank gases which may be found in the shelters [38].

NO_2. Human poisonings with nitric oxides are unknown, but nitric oxide and nitrogen dioxide are considered toxic gases. Exposing animals to NO_2 at 5 ppm showed zero per cent mortality with monkeys, 18 % with rats and 13 % with mice[68]. Chronic lung diseases have been produced experimentally by giving nitrogen dioxide, but most of the experimental work done to date analyzes nitric oxides in low but irritating levels. NO_2 is produced by burners and smoking[38].

Hydrogen Sulfide. In small concentration this gas is irritating because of

the odor. Concentrations above the irritation level have not been studied experimentally, but it is known that high concentrations are toxic and may produce a systemic effect resulting in death.

Other gases which may occur in the internal environment of the shelter may be NH_3 (one hour threshold 0.04 %), CH_4 from the sanitary tanks, Cl_2 from chlorate candles or other sources such as household bleaches (highly toxic, 1 hour threshold less than 0.5 ppm).

PHYSIOLOGICAL, BEHAVIORAL AND OTHER HUMAN ENGINEERING FACTORS

Synergistic Effects

The human response to mass fire conditions presents a very challenging and complex problem of synergistic or combined effects of health hazards. A direct relationship between physical data and biological response cannot always be established. The multiple effect of hazard response can be seen when two or more stresses cause a greater response when combined than could be predicted by adding the individual responses.

Brooks et al.[69] observed over six fold increase in lethality (12 to 73 %) from a standard burn in dogs when 100 R of total body gamma radiation was given in conjunction with the thermal effects. This amount of radiation when given alone was not lethal. Noxious gases such as nitrogen oxides and sulfur dioxide which combine with hemoglobin act synergistically with carbon monoxide.

In air pollution studies, it has been demonstrated that SO_2 potentiates the inert particulates[70]. Some studies show that guinea pigs exhibited greater pulmonary flow resistance when exposed to equivalent amounts of SO_2 and sub-micron particles of H_2SO_4 than from twice the concentration of either alone[71]. As with other studies presented here, it is noteworthy that the conditions of mass fire have not been studied in relation to synergistic or combined effects; and that under fire conditions these individual hazards and biological responses may be even higher.

Alcohol may have the same effect with CO. Moureu[72] in a survey of traffic exposed persons made an interesting observation; he found that intoxicated drivers had much higher blood carboxyhemoglobin than controls exposed to CO levels found on highly traveled streets. This has not been substantiated with dog studies, however.

Dean and McGlathen[73] showed that various combinations of hypoxia, heat and noise were additive in their effect on biological response and on the performance of primary and secondary tasks. Each stress alone was mild and showed no effect on the physiological or performance response. Work is being done on the possible synergisms to be expected with radiation and heat [15]. Much work has been done with radiation in combination with other stresses[74].

Physical Condition

The physical condition of individuals affects the response to stress. If cigarette smoking has weakened the lungs, the additional stress on respiration may be much more severe than on a non-smoker. A person with kidney disease will be less able to handle certain particulate elimination such as lead and therefore have lower limits of toleration. High temperatures also increase this hazard[75].

The fitness of the individual influences his oxygen consumption rate; in exercise this then can add to the stress of hypoxia. Age is a factor which can alter the response to certain health hazards. Young and healthy people may be affected more quickly than older persons because their active metabolism may lead to a faster absorption of gases. Pregnancy decreases tolerance to O_2 deficit and other factors such as CO, which would decrease the amount of O_2 available to mother and fetus.

Other Combined Effects

It has been reported that when acid is added to the blood, the respiratory volume will increase in response to the activation of various chemoceptors in the body. Certain drugs will produce an increase or decrease in lung ventilation[40]. The relationship of this to particulates and noxious gases is important. Since a large percentage of the population takes some type of medication at one time or another the combined effects of health hazards with various types of drugs, especially those proprietary or ethical drugs which are commonly used or prescribed, may be a worthwhile study. In the mixed population of shelter occupants there will be a reasonable percentage of people taking drugs, whether it be an aspirin, tranquilizer, diet pill or prescription drugs for heart conditions, respiratory or infectious conditions, etc.

An example of combined compensating physiological and psychological reactions which could magnify the total responses would be the following: An increase of CO_2 up to 9 % in air level can be tolerated for short periods without damaging effects. The adaptive biological response is to increase ventilation rate. This hyperventilation is tolerable for some time, although a slight dizziness occurs. However, if the hyperventilating subject were sitting in a smoky room with low concentration of particulates, in a very

short time his lungs may be clogged with enough particulates to cause difficulty in breathing. This decreased efficiency in ventilating the lungs coupled with a lowered ambient O_2 furthers the distress. An additional load of heat and anxiety would increase the probability of collapse. All these factors of themselves were determined to be subliminal and may or may not have been categorized as health hazards. Because of the combined effects upon one another, however, otherwise apparently innocuous levels become toxic levels. It is only through a correlation of physical measurements with biological responses that these combined effects become evident.

Behavioral Factors

It has been suggested that survival in the Hamburg and Dresden fires depended largely upon what people did and where they were at the height of the fires[59]. Those who kept their heads and proceeded according to some predetermined plan had a better chance for survival. It has also been suggested that whole groups survived because they had been trained and conditioned to follow instructions from appointed leaders, not so much because the actions taken were protective or beneficial, but more because they helped to avoid panic and hysteria.

Although there is some understanding of the human tolerance to heat, noxious gases and the effects of various factors such as age, sex, and physical condition on tolerance, the contribution of various human behavioral factors to expected survival rates under mass fire conditions has not been determined.

It has been suggested that any distressing incident, such as someone fainting, could trigger a mass hysteria which may be more hazardous than the other factors and could endanger the whole protective machinery. Some efforts have been made to predict psychological reactions expected after a disaster[77]. The use of various tranquilizers to induce a relaxed state may be suggested. However, an overconfident state may be equally dangerous, as was the case with some shelter occupants during the Hamburg fires who died in their sleep because they had failed to realize the necessity of using protective devices against heat and toxic gases[59].

Separation of family units may cause severe psychological distress. Animal experimentation where a mother was separated from her young has borne this out. Anxiety caused physiological responses as well as outward signs

of emotional disturbance.

The physical aspects of mass fire such as the roaring of the winds and flames, the crashing of gutted buildings, flashing lights and explosions may be frightening to adults, and most certainly to children.

All these emotional states are accompanied by physiological responses. Obvious signs are increased heart rate, respiratory rate and blood pressures; the amount of elevation is dependent upon the severity and duration of distress. This is due to the homeostatic response of increased secretion of adrenalin during excitement or anxiety. Elevated blood levels of adrenalin affect the balance of specific organ systems and their metabolic function. Although the physiological responses are adaptive and are the body's protective mechanisms, these responses can sometimes be deleterious and impair performance. Under nervous stimulation, the blood is normally diverted from the digestive to the brain nerve centers and other essential organs and muscles. The purpose of this is to prepare the body for either fight or flight. However, excessive nervous tension could induce vomitting and diarrhea and excessive voiding which could lead to dehydration, resulting in an imbalance of metabolism and other functions. In addition to the obvious psychological problems this would cause among shelter occupants, secondary problems such as increased load on the shelter waste disposal system, etc., could result.

Human Engineering and Shelter Management

Many studies have been conducted by OCD which have dealt with the human engineering factors and have demonstrated the overriding importance to shelter management and survival. It has often been suggested that many survivors of the German city fires had been drilled in strict military-type discipline since early childhood, and that this prior intensive training enabled them to follow instructions and command almost instinctively and that this was a very important factor in ultimate survival.

The value of some type of mass education and training program to acquaint the general public with the mass fire problem, its hazards and protective measures may require investigation.

Previous shelter studies were directed primarily toward protection from fallout and blast. Public attitudes and public acceptance of OCD shelter philosophy may have been influenced by their relative inability to fully

comprehend the dangers of an "unseen" hazard. Further confusion concerning radiation was also undoubtedly added by the highly publicized, often widely conflicting opinions of various groups of "experts" concerning the actual hazard involved.

The concept of large scale fires and the attendant hazards does not suffer from this. Fires are a familiar problem easily comprehended, since every individual has, at one time or another, been exposed to its dangers. The association of the shelter as a protective device against a known and identifiable hazard may be a very important factor in promoting the usefulness of protective programs.

The need for more realistic training in fire safety and fire fighting procedures has been suggested. School fire drills in this country are little more than welcomed unscheduled recesses from normal classroom routine. Would the drills be more effective if they were carried out under more realistically simulated fire conditions? Would school children and their adult escorts still troop out of the building so casually and indifferently if actual flames and smoke were present?

In addition to problems concerning the general shelter occupant, there is also an obvious need for a specially selected and trained group or 'cadre' of leaders equipped with adequate knowledge and training to cope with all the problems involved in shelter management for survival under mass fire conditions.

BIOLOGICAL TEST DESIGN

Physical Vs. Biological Testing

In general, physical phenomena respond according to fairly straightforward (stoichiometric) laws of behavior and it is usually possible to scale experiments up or down in magnitude or duration and be able to predict with some reasonable degree of success the probable results. Thus it is often possible to simulate or duplicate certain facets of a physical experiment on a laboratory scale. These experiments can often subsequently be incorporated into large scale field tests with a minimum of additional tie-in effort. Also there are generally only a limited number of factors involved in most physical experiments and these parameters are often relatively easy to identify and control.

In biological testing, however, and especially with a biological system as highly developed as man, predicting the overall system response to alterations of external environment constitutes a much more difficult task. Even where the external environment is relatively uncomplicated or perhaps artificially controlled as in the case of high altitude or space simulation, the net overall biological system response often cannot be reliably predicted in advance without the benefit of full-scale field testing.

In the case of the much more complicated external environment presented by the mass fire or fire-storm concept with its many variables and inadequately characterized, often unidentified hazard factors, the prediction of the biological system response from a consideration of certain physical measurements made in the field becomes very risky indeed.

The complicated network of synergistic, antagonistic, adaptive, psychological and other responses which make up man's biological system may respond positively to a given hazard factor under one set of conditions and negatively under conditions only slightly different. Likewise it should be pointed out that candidate protective mechanisms may be beneficial in one or more respects but may add to or further complicate the hazard picture in other respects.

When sufficient information is obtained by whole system testing it is often possible to break the system down into smaller parts and investigate details in the laboratory. Also it is true that much useful information of a simple exploratory or "shotgun" type can be gained from physical measurements made on small scale laboratory or field experiments which attempt to simulate

the actual conditions. However, in the final analysis the best way to verify laboratory findings and certainly the only way to evaluate protective mechanisms is to expose complete biological test systems to the complete experimental environment.

The Controlled Biological Experiment

To the uninitiated it may seem that the almost infinite number of variables presented by a complex biological system exposed to an uncontrolled, largely unknown environment makes the task of obtaining useful and practical information for hazard evaluation and protection purposes very diffucult, if not impossible. Yet such a situation is almost made to order for investigation by the classic biological approach. The biological scientist has at his command a powerful and versatile investigative tool which is both elegantly simple and dramatically effective. This is known as the controlled biological experiment. In its simplest form the controlled biological experiment consists of exposing two identical groups of test subjects designated as the control and test groups to exactly the same environmental conditions. After establishing that the "normal" response is the same for both control and test groups, the experimental environment of the test group is then carefully varied or controlled in terms of the factor or condition being investigated, meanwhile maintaining the control group under the original unaltered environment. Under these conditions any significant difference in response between the two groups of subjects can be attributed to the effect of the test variable on the overall biological system. It is obvious that for this method to be valid and avoid the risk of misinterpretation of the results, extreme care must be taken to insure that the control group experiences exactly the same test conditions in all respects as does the test group, with the single exception of the variable condition under investigation. An example of how this approach can be misused and often erroneous or questionable conclusions drawn from inadequately controlled experiments would be the case of various toothpaste tests where one group of subjects used the sponsor's brand and another group used exactly the same formulation with the "key ingredient" left out. Results of these tests do not necessarily show that the incorporation of ingredient "X" causes fewer cavities since no attempt was made to establish a baseline showing that in the absence of ingredient "X" the response for the two groups would be identical. Some of the other "outside" factors which would

have to be closely controlled in order for test results to be meaningful include diet, eating habits, dental hygiene, even possible differences in the quality of drinking water.

It is true that especially in the preliminary phases of any investigation the biological scientist often finds it necessary or expedient to use a shotgun approach to obtain grab samples of the unknown environment. These grab samples may often yield valuable clues as to the nature or extent of the problem. Sometimes on the strength of his intuitions (or perhaps an educated guess or two) he may even contemplate fielding a small number of uncontrolled biological experiments to further confirm his suspicions. This is an accepted and often necessary procedure in the logical development of any new experimental research program. However, it should be emphasized that the results of such simple uncontrolled experiments are only indicative at best and definitively not conclusive. They are useful in providing input for more sophisticated and properly controlled laboratory and field experiments to follow up and prove out the leads furnished. Much of the experimental work which has been carried out to date in exploring the various aspects of mass fire life hazard falls into this exploratory category. The experimental burns of Broido and McMasters, the various building burns reported by ITTRI, the gas samples taken by Countryman, Bush and others have given us valuable insight into various hazard aspects of mass fires.

Preliminary lab and field testing is necessary, especially for the lesser known hazard factors and should be continued. On the other hand, the biological scientist must take every precaution to anticipate and eliminate any source of variation due to "outside" factors which may complicate or even invalidate the results of otherwise carefully planned and executed experiments. Only in this way can the proper interpretations and sound conclusions and recommendations be made.

Choice of Test Subject

Since the ultimate program objective is the protection of human shelter occupants, the ideal test subjects would be actual human beings. Indeed many successful field tests on shelters have actually been carried out using human volunteers. However, such tests are justified only where the hazards are well defined and adequately controlled, the shelter protection has been proven to be more than adequate and the factors under study are the more subtle "human" engineering aspects of shelter occupancy.

At the present state of development and knowledge of the mass fire phenomenon coupled with our lack of well-established and field tested guidelines for hazard evaluation and control, the use of human volunteers is out of the question.

Until such time as human test subjects can safely be used, the scientist must turn to other suitable biological test subjects to carry out the field experiments. Most commonly used are various small laboratory animals. There are several important considerations in determining the choice of animal species for a given field experiment.

a. Biological response closely similar to man.

b. Easily available in large numbers at low cost.

c. Homogenous population to minimize individual differences.

d. Ease of maintenance and transportation.

e. Public attitude concerning use.

From the standpoint of the above considerations, the choice narrows down to the use of either closely inbred laboratory mice or rats. Dogs and cats would not be acceptable because of their common status as household pets. Monkeys would not be suitable because their well developed adaptive responses create large individual differences. Rabbits, guinea pigs, and hamsters are expensive to obtain and maintain in large numbers. In addition, all these animals would be more difficult to transport through hot, dry country because of their size than either mice or rats.

Of the two, rats are probably better for those experiments requiring measurement or observation of individual animals because of their larger size whereas mice would be more convenient for mortality-survival types of tests. Group and individual differences for both rats and mice have been pretty well eliminated through intensive laboratory breeding programs. Many large research animal colonies exist in this country today where carefully selected strains of both types of animals are maintained and reproduced in large quantities suitable for laboratory and field testing.

Biological Indices

Field testing with laboratory animals is necessary for two purposes:

a. Identification and characterization of hazard factors.

b. Evaluation and verification of protection factors provided by various mechanisms.

Obviously, in the case of the better known hazard factors such as heat and asphyxiation, the emphasis will be more on the protective mechanisms except perhaps in cases of suspected interactions with other hazard factors or possible influences of various countermeasures or preventive mechanism. Depending on whether the objective is (a) or (b), different biological end-points or indices would be used. For hazard detection and identification very sensitive qualitative information is required. The test animal is used mainly as the sensor or detector of the system. The readout is in the form of various instruments which monitor the degree of well-being or physical discomfort of the test subject. This type of test data is far more significant than simple mortality-survival tests for hazard evaluation purposes. Mortality-survival tests are a measure of the severity of the overall combination of hazard factors which is a necessary step in establishing the base-line for protection studies, however, mortality is a very poor indicator for identifying the individual hazard factors. We are well aware that acute problems in shelter occupancy management can arise when physical hazard factors are still far below the lethal levels. If even one occupant of a shelter were to collapse from nausea or fright or lack of physical conditioning, it would create a crisis within a crisis which would complicate the problem of shelter management and greatly lessen the chances for survival of the others.

For determining protection factors on the other hand, qualitative information is less useful and actual numerical or quantitative results are needed. In specifying the degree of protection afforded shelter occupants, we must be able to state that for any given protective mechanism there is 100 %, 200 % or 300 %, etc. safety factor for the degree of hazard expected. One should be able to scale up to the worst possible circumstances for which complete protection is afforded. For this type of test the animals are used mainly as indicators or read-out mechanisms. The combinations of known hazards is increased in severity until in the absence of the added protection a high percentage of mortality is obtained in the control group. A decrease in mortality of the test group would be an indication of the effectiveness of the protection afforded. For tests of this type, survival figures of 0 % and 100 % are less meaningful than say 10 % and 90 %. The environment to which both groups are exposed is carefully monitored with instruments to insure validity of the results and reproducibility from experiment to experiment.

As each protective mechanism is incorporated into the control group, the severity of the environment can be scaled upwards in order to test other additional protective mechanisms or to probe the upper limit of protection.

Relation to Other Fields of Study

In both hazard and protection areas, there is need for a continuous and closely correlated program of laboratory and other studies. Once a hazard factor has been identified or established, it is often more convenient and expedient to isolate the mechanism for further study in the laboratory. In the case of hazards or suspected hazards associated with secondary factors such as shelter design, construction or management as opposed to those strictly introduced by the mass fire itself, these can be pursued completely independent of the mass fire studies. The same applies to education and training programs, public opinion studies and the like which are conducted in the classroom, in the streets, and through various media for communication with the public. As results of these related studies become available, they can be incorporated into the overall field operations test plan.

PRACTICAL FIELD TEST DESIGNS

As we have already inferred, not all the program objectives of Operation Flambeau are suitable for investigating by field testing. For the results of field tests to be most meaningful, many related studies are indicated which are better carried out in the laboratory and elsewhere. In formulating test designs for the field, one must always be aware of the interrelationship of such studies. Since the detailed design of many field experiments depends on input being available from related laboratory work which must precede it, the following discussion is intended only to introduce the reader to the types of tests best suited for field experimentation and the manner in which such tests would be implemented and carried out.

Tests for Heat

Many worthwhile studies have been conducted on body and environmental heat as factors in shelter occupancy tests(16). Field tests on heat would be devoted mostly to evaluating protective mechanisms and to investigating possible interactions with other known or unknown hazard factors or proposed counter measures or protective mechanisms.

To evaluate the degree of protection afforded against heat alone, it is necessary that both test and control groups be isolated from all other hazard aspects of the external environment or, at least, that both groups be exposed to all other hazards in the same degree. The latter is often difficult to control since often the mechanism which protects against heat operates on other hazard factors as well or else the protective mechanism itself may possibly constitute an additional hazard. For instance, it is believed that the use of smoke screens may be beneficial in reducing heat transmitted through the air. On the other hand, it is important to determine that various materials used in generating smoke screens do not add to and complicate the hazard picture. One way to avoid this problem is to enclose the test animals in a completely self-contained atmosphere allowing only the temperature to vary. Protection afforded by various shelter construction materials and designs may be evaluated in this manner(80). Often it is difficult to separate protection factors within the same experiment. In these cases, one must be careful no synergistic or antagonistic effects are at work. For instance, various means to cool the incoming air to a shelter may be tested. Almost all these mechanisms for cooling would have some effect

on the gaseous make-up of the treated air also. Thus, if the air temperature is cooled by allowing it to enter through some large sub-terranean vault or tunnel (which would simulate existing void spaces and heat sinks such as sewers, subway tunnels, etc.), the peak concentrations of CO and other noxious gases would be flattened out also. The danger in a situation like this is in implying more protection factor than actually exists because we are removing a possible synergistic effect. Even when mortality or survival is being used as an absolute end-point for protection experiments, both control and test groups require accurate instrumental monitoring throughout the test. Suspected cases of synergism or antagonism would then be studied in the laboratory by accurately duplicating field conditions.

Tests for Common Respiratory Gases

Field tests for the common respiratory gases would also emphasize protection rather than hazard investigation. In the case of gases, however, the results can be separated from the possible effects of heat by the use of external cooling devices either for the incoming air or for the test chamber itself. Care must be taken to insure that the cooling mechanism itself does not affect the experiment. This is automatically compensated by using the same pre-cooled air to ventilate both groups of animals.

For example, it has been reported that sand filters and similar heat sinks provide little if any protection against dangerous gas concentrations. Yet it is possible that such approaches may be useful in controlling high peak concentrations of CO and other gases especially if the volume of the filter bed is large. By acting as a large buffer tank of safe air which dilutes the peak concentrations to tolerable levels, such filters may actually offer some real degree of protection.

This would be a fairly simple field experiment to set up. Both control and test groups of animals would be housed in suitable underground test chambers through which temperature controlled air from the mass fire environment is pumped. The air is sampled from a point where previous baseline studies have indicated that in the absence of protection against gases a significant number, say 90 %, of the animals would succumb. The unprotected group thus becomes the control for this series of experiments. The same air is pumped to the test group(s) except that it is first routed through the protective mechanism, in this case the sand bed filter. Increase in survival

rates would indicate a beneficial protective effect. A variation would be to test a series of sand filters of increasing size and perhaps compare the results with simple air tanks (without sand) of the same size.

This same approach would be used to test the effectiveness of various commercial devices for purifying air which use Baralyme, activated charcoal, and other chemical or physical reactions. As in the case of heat, suspected cases of interactions with other factors can be explored in a preliminary manner in the field but detailed studies on isolated mechanisms are probably best carried out in the laboratory.

Test for Lesser Known Hazards

As we leave the better known hazard aspects and get to the lesser known factors the emphasis in testing shifts from evaluating protective mechanisms toward the more detailed investigation of the hazard factors as such.

The most obvious of the lesser known factors is, of course, smoke. In spite of the fact that many hundreds of cases of casualities from smoke inhalation are reported each year we still know very little about the actual biological mechanisms involved. This is because, among other reasons, smoke is such an ill-defined term. The smoke that is produced by burning woodland fuels may be quite different in hazard effect from that produced by burning various materials used in home or shelter construction. It has been demonstrated that the same sample of fuel produces smoke of widely different physical appearance when heated and burned at two different rates[78]. Many observers are of the opinion that true cases of fatalities from "smoke inhalation" are rare and that most victims really succumb because of asphyxiation or CO poisoning.

These considerations suggest various simple tests that could be fielded that would be of value from a preliminary or exploratory nature. Smoke could be sampled from different parts of the mass fire, at different times or at different heights in the smoke column and passed through test chambers containing the control and test groups. The control group would have the air passed through a filter and scrubber which would remove particles and soluble chemicals, but would permit the common respiratory gases to pass through unchanged. In this way one could determine the relative toxicity of smoke produced at different locations and stages of the mass fire. For recording the effects of smoke inhalation, we would probably need to rely a good

deal on visual observation of test animal response. This would not be a problem in the laboratory but field testing may require the use of some remote viewing device such as closed circuit TV.

Similar tests could be envisioned for the other situations, however, it is apparent that most of these tests require additional input that can best be obtained in the laboratory or with small scale test burns. For instance, the smoke from typical woodland fuels could be compared with that produced by burning various smoke-producing materials often used in home or shelter construction such as rubber, plastic, plaster, asphalt, paints, etc. In this case, two identical test fires would be built, one containing woodland fuels only, and the other with the suspected smoke producer added. Evidences of increased toxic effect would be determined by instrumental monitoring, visual observation and organ examinations.

After the potentially hazardous smoke producers have been identified, experiments with different rates of heating can be devised to test whether smoke produced from these materials during normal building burns differs in toxic effect from smoke produced under mass fire conditions. (One should not exclude the possibility that many materials deemed "safe" at ordinary dwelling fire temperatures may behave quite differently at the much higher temperatures encountered in mass fires.)

For studies of protective mechanisms, we would reverse the situation for the above tests. The unprotected group becomes the control and the protected group is the test population. Conditions would have to be scaled up so that a predictably large mortality rate would be observed in the unprotected control group. Effectiveness of the protection afforded is gauged by the increased survival of the protected group.

Many additional studies can be carried out in the laboratory on individual types of smoke. These would help to answer questions whether the principal mechanism is simply mechanical obstruction, adsorption of toxic substances onto the particles of smoke, or perhaps due to gases, chemicals or other toxic agents co-produced with but not really related to the smoke itself. Obviously, answers to questions of this type are needed before effective protective measures can be devised and field tested.

Hazards which may arise from less obvious sources such as shelter contents and equipment, methods of firefighting, various counter measures,

etc., would require even more preliminary laboratory and small scale exploratory testing than smokes before any meaningful field testing could be contemplated. Here the testing would be largely of the uncontrolled grab sample type. For instance, it has been suggested that common fertilizer mixtures would be good for putting out small fires. Others have argued that depending on the composition of the fertilizer, more harm than good may result since toxic oxides of nitrogen or even phosgene may be produced. One could spike a test pile with various fertilizers and determine if under conditions of the mass fire any toxic substances are produced.

These could be tested by comparison with results obtained from a similar test pile without the added fertilizer. A small number of animals may be placed under each pile for direct observation, however, for most exploratory tests of this type, samples obtained in the field would be taken back to a laboratory for further study and analysis.

Test for Behavioral Factors

The study of the effect of education, training, conditioning and other behavioral, adaptive and "human engineering" factors on shelter survival under mass fire conditions is more properly conducted for the most part in the laboratory, in classrooms, at information research centers, through public opinion surveys, personal contacts and interviews with professional fire fighters and surviving victims of actual fires, etc. Actual field testing of human engineering factors would probably not be attempted until there is reasonable assurance that all important physical hazards have been identified and completely adequate shelter protection has been developed.

The detailed design of such tests is clearly outside the scope of the present work. Many successful programs of this type have been sponsored and carried out under OCD auspices in connection with regular fallout shelters. Most of these programs will probably need to be re-evaluated in terms of the augmented hazard environment.

It is possible, however, to formulate a few simple field test designs which would serve to demonstrate the importance of this aspect of shelter survival. For instance, to demonstrate the effect of emotional stress on survival rates, we could subject the test group of animals to loud noises, flashing lights, etc. which would put them in a highly excited state. The control group would be in a similar sound-proof and light-tight enclosure

isolated from these effects. Both groups would be exposed to the mass fire elements (piping in hot gases, smoke, etc.) in an amount which would not normally produce casualities in the control group. Decreased tolerance by the excited test group would confirm the presence of a contributory effect.

The probable value of prior conditioning or training could be demonstrated in a simple way by previously exposing the test animals to the loud noises or flashing lights until they have completely adapted to the added stimulus.

The possible benefit of using various drugs or chemicals to induce calm as a means of reducing casualties could also be explored in the same simple manner.

FACILITIES, EQUIPMENT, PERSONNEL

It is obvious from a consideration of the types of tests described in the previous sections certain minimum facilities for care and maintenance and transportation of the necessary test animals are required. On a field visit to the site of Forest Service burn experiments near Mono Lake, California, it was determined that virtually no facilities exist at present for handling experimental animals in the field. Furthermore, the very nature of large scale burn experiments requires that the burn sites shift from location to location as the fuel supply is used up. The Forest Service type fires are conducted on open land away from population centers often in the middle of hot desert country. On the other hand, building burns and laboratory scale experiments are usually conducted close to large urban population centers. Most of the related human engineering studies would also be conducted at information research centers located in heavily populated urban areas. Nevertheless, it is essential to the ultimate program objectives of Operation Flambeau that effort in all these areas be closely coordinated and integrated. One way to implement this would be the establishment of permanent or semi-permanent field laboratory facilities for all mass-fire oriented research. This facility should be far enough away from large population centers so that small scale test fires can be built on the premises yet close enough to major information research centers to encourage close cooperation and interchange of information. Provisions should be available for maintaining a good size animal colony and for carrying out the laboratory scale physical and biological investigative experiments. A suitable location for such a facility may be found in the Camp Parks, California test site. Camp Parks has been used successfully in the past for both fallout and fire shelter studies. The U.S. Naval Radiological Defense Laboratory has developed a large animal colony on the site and the U. C. Lawrence Radiation Laboratory is in the process of creating additional laboratory animals research facilities here. Camp Parks is within easy traveling distance of USNRDL, SRI, USFS in Berkeley and is reasonably close to the present burn sites at Mono Lake so that transporting animals back and forth is not out of the question. Besides Camp Parks, there are undoubtedly other suitable sites for such a field test laboratory which may be considered.

In addition to the permanent field laboratory it is important that some physical transitioning device be developed to permit data obtained in the laboratory to be more useful in setting up field experiments and to obtain better correlation of results obtained with field test fires of various types including Forest Service burns, urban building burns, and other fires of opportunity such as forest fires, large residential fires, etc. A practical solution to this problem would be the design and development of a standard test shelter for mass fire investigation. The test shelter should be large enough to accommodate the necessary animal experiments. Provisions should be made for controlling and monitoring of the internal environment. A shelter design that is smaller than 25 feet long by 25 feet wide could be placed underneath one of the standard brush piles used in current Forest Service test burns and still be large enough to carry out almost all the preliminary biological tests which have been discussed. For less hazardous test locations, one or more fire researchers could actually work inside such a shelter. Such a basic "shelter laboratory" would be useful for the study of a variety of other mass fire problems also.

DISCUSSION AND CONCLUSIONS

It is apparent that much needed information concerning the hazards faced by shelter occupants exposed to mass fire conditions and the mechanisms for protecting against these hazards can be gained from a properly designed program of biological field testing. Information provided by such tests is important not only for Civil Defense disaster planning and management purposes, but would be of vital interest to other fire fighting agencies responsible for putting out building burns, forest fires and industrial conflagrations.

At the present time, large scale biological field testing would of necessity be limited to the more obvious hazard factors and protective mechanisms. More extensive investigation is needed at the exploratory and laboratory levels on the lesser known hazard factors before these can be incorporated into the overall field testing program.

Reference has been made to behavioral, sociological and other "human engineering" response which may have an over-riding influence on the entire hazard picture and are, therefore, critical factors in the overall OCD problem of shelter occupancy and management.

At present, the most pressing need is for establishment of suitable laboratory and field facilities necessary to carry out the indicated long range biological test programs. In addition, physical means are required to permit proper integration and correlation of data obtained from related testing being carried out at other locations. Suggested solutions for both these problems are presented.

REFERENCES

1. Bond, H., Fire and the Air War. Boston, Nat'l Fire Protect. Assoc., 262 pp. (1946).

2. Glasstone, Samuel, Ed., The Effects of Nuclear Weapons, prepared by U. S. Dept. of Defense, published by U. S. Atomic Energy Commission, Rev. Ed. (February 1964).

3. Civil Defense - Project Harbor Summary Report, Nat'l Acad. of Science, Washington, D. C. (1964).

4. The Committee on Fire Research, 1 July 1962 - 30 June 1965, prepared for Nat'l Acad. of Sciences. Nat'l Acad. of Sci. - Nat'l Res. Council. Washington, D. C (1965).

5. Countryman, Clive M., Mass Fire and Fire Behavior, USFS Research Paper PSW-19, Pacific SW Forest and Range Experiment Station (1964).

6. Parker, W. J., Thermal Hardening Considerations Pertaining to Residential Areas. USNRDL-TR-984, U. S. Naval Rad. Def. Lab., San Francisco, California (24 February 1966).

7. Rodden, Robert M., Floyd, I. John, and Richard Laurino, Exploratory Analysis of Fire Storms, S.R.I. Project MU-5070, Menlo Park, California (May 1965).

8. Strope, W. E , Porteous, L G., and A L. Greig, Specifications and Costs of a Standardized Series of Fallout Shelters. USNRDL-TR-366, U. S. Naval Rad. Def. Lab., San Francisco, California (1959).

9. Piel, Gerard, The Illusion of Civil Defense, Bulletin of the Atomic Scientist (February 1962).

10. Broido, A. and A. W. McMasters, Effect of Mass Fires on Personnel in Shelters. U.S.F.S. Dept. of Agriculture, Berkeley, California (1960).

11. Evans, E. C., III and E. T. Tracy, Observations of Mass Fire 460-14 at Mono Lake. U.S.N.R.D.L., San Francisco, California (1966).

12. Waterman, Thomas E., Shelter Habitability in Existing Buildings Under Fire Exposure, IIT Research Institute, Chicago, Illinois (1966).

13. United States Strategic Bombing Survey, Physical Damage Division Report (ETO), Physical Damage Division (April 1947).

14. White, Clayton S., Brown, Gerald I. and Donald R. Richmond, Biological Tolerance to Air Blast and Related Biomedical Criteria. CEX-65.4 AEC (1965).

15. Pryor, A. J., Mass Fire Life Hazard, Progr. Rep. No. 3 (1966), Southwest Res. Inst., San Antonio, Texas.

16. Strope, W E., Schultze, D. P. and J. I. Pond, Preliminary Report on the Shelter Occupancy Test of 25-29 July 1960. USNRDL-TR-502 (March 31, 1961).

17. Pryor, Andrew J. and Calvin H. Yuill, Mass Fire Life Hazard, Progr. Rep. No. 2 (1965), Southwest Res. Inst., San Antonio, Texas.

18. Behls, H. F. and C. A. Madson, Experimental Studies of Fallout Shelter Ventilation Requirements, GARD Report 1268-40 (1965). AD 630 423.

19. Simulated Occupancy Test Underground Concrete Structure Lakeside, California, Engineering and Industrial Experimental Station, University of Florida, Gainesville, Florida.

20. Smith, J. B., Cousins, E. W., Miller, M. J. and R. M. Newman, Fire Safety Upgrading for Fallout Shelters in Buildings AD 610 819 (1964), Factory Mutual Research Corporation, Norwood, Mass.

21. Rubner, M., Die Quelle der Thierischen Wärme Z. Biol. 30:73 (1894).

22. DuBois, D. and E. F. DuBois, Clinical Calorimetry. A formula to estimate the approximate surface area if height and weight be known. Arch. Intern. Med. 17:863 (1916).

23. Kleiber, Max, Body Size and Metabolic Rate. Physiol. Rev. 27:511 (1947).

24. Morehouse, L. E. and A. T. Miller, Physiology of Exercise, 3rd Ed., C. V. Mosby Co., St. Louis (1959).

25. Winslow, C.-E. A., Herrington, L. P. and A. P. Gagge, Physiological Reactions of the Human Body to Varying Environmental Temperatures. Am. J. Physiol. 120:1 (1937).

26. LeFebre, J., Thermoregulation et Rendement du Travail de la Machine Vivant, en Fonction de la Temperature Exterieure. Ann. de Physiol. 11:942 (1935).

27. DuBois, E. F., Basal Metabolism in Health and Disease, 3rd Ed., Philadelphia, Lea and Febiger (1936).

28. Pitts, G. C., Johnson, R. E. and F. C. Consolazio, Work in Heat as Affected by Intake of Water, Salt and Glucose. Am. J. Physiol. 142:253 (1944).

29. Adolph, E. F., Physiology of Man in the Desert. Interscience Publishers, Inc., New York (1947).

30. Hall, J. F., Jr. and F. K. Klemm, Insensible Weight Loss of Clothed Resting Subjects in Comfort Zone Temperatures. J. Appl. Physiol. 18, p. 1188 (1963).

31. Santamaria, L. J., Klein, S. J. and H. R. Greider, The Maintenance of Thermal Comfort in a Full Pressure Suit at Simulated Altitude. Aerospace Medicine 31:288 (1960).

32. Leithead, C. and A. R. Lind, Heat Stress and Heat Disorders. F. A. Davis Co., Philadelphia (1964).

33. Kissen, T. T. and J. F. Hall, Physiologic Response to Transient Heat Stress in Reflective Versus Non-reflective Clothing. AMRL TDR 63-79, 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio (1963).

34. Kaufman, W. C., Human Tolerance Limits for Some Thermal Environments of Aerospace. Aerospace Medicine 34:889 (1963).

35. Webb, P., Pain Limited Heat Exposures. Ch. 4, p. 245, ed. Charles M. Herzfeld. Temperature: Its Measurement and Control in Science and Industry. 3, Part 3, Rheinhold Publishing Company, New York (1963).

36. Adapted from North American Aviation unpublished data. Bioastronautics Data Book, NASA (1964).

37. Sollman, T., Systematic Action of Gases, A Manual of Pharmacology. 7th Ed., W. B. Saunders Co., Philadelphia.

38. Goldsmith, Air Pollution. Ch. 10, ed. Arthur C. Sterns, Academic Press, New York (1962).

39. U. S. Navy Submarine Atmosphere Habitability Data Book Navships No. 250-649-1, Rev. No. 1, Bureau of Ships, Navy Dept., Washington, D. C. (1962).

40. Boothby, W. M., Handbook of Respiratory Physiology, Air University USAF School of Aviation Medicine, Randolph Field, Texas (1954).

41. Comroe, J. H., Forster, R. E., DuBois, A. B., Briscoe, W. A. and E. Carlsen, The Lung: Clinical Physiology and Pulmonary Function Tests, 2nd Ed., Year Book Medical Publishers, Inc., Chicago (1962).

42. Brown, referenced in Boothby, Handbook of Respiratory Physiology, Air University USAF School of Aviation Medicine, Randolph Field, Texas (1954).

43. Weeks, M. H., and P. P. Yevich, The Toxicity of Combustion Products of Pyrotechnic C.W.L. Tech. Memo. 26-12 (1959).

44. Haldane, J. S., Carbon Monoxide Poisoning in Man. Brit. Med. Journ. 2:16 (1930).

45. Barcroft, J., The Respiratory Function of the Blood. Cambridge University Press, New York (1925).

46. Henderson, Y., Adventures in Respiration, Williams and Wilkins Co., Baltimore (1938).

47. Roughton, F. J. W. and R. C. Darling, Am. J. Physiol. 141:17 (1944).

48. Earp, K. F., Deaths from Fire in Large Scale Air Attack (with special reference to Hamburg Fire Storms). Home Office (United Kingdom)(1953).

49. Henderson, Y., and H. W. Haggard, The Treatment of Carbon Monixide Asphyxia by Means of O_2-CO_2 inhalations. J.A.M.A. 79:1137 (1922).

50. Haldane, J. S., Report of the Board of Trade on the Ventilation of the Metropolitan Railroad Tunnels. Parliamentary Paper 68684 (1897).

51. Lewey, R. H. and D. L. Drabkin, Experimental Chronic Carbon Monoxide Poisoning of Dogs. Am. J. Med. Sci. 208:502 (1944).

52. Chornyak, J., and R. R. Sayers, Studies in Asphyxia, Neuropathology Resulting from Comparatively Rapid Carbon Monoxide Asphyxia. U. S. Public Health Report 41:1523 (1931).

53. Halperin, J. Physiol. 146:583 (1959).

54. White, P. A., Brahdy, L., and S. Kahn, Trauma and Disease, Lea and Febiger, Philadelphia (1937).

55. Stearns, W. H., Drinker, C. K., and T. J. Shaughnessy, Electrocardiograph Changes in 22 Cases of Carbon Monoxide (Illuminating Gas) Poisoning. Am. Heart 15:434 (1938).

56. Lindgren, S. A., Acta Med. Scandinav. 167:1 (Suppl. 356)(1961).

57. Sievers, R. F., Edwards, T. I., and A. L. Murray, A Medical Study of Men Exposed to Measured Amounts of Carbon Monoxide in the Holland Tunnel for 13 Years. U. S Pub. Health Bull 278 (1942).

58. Farmer, C. J. and P. J. Crittenden, A Study of the CO Content of the Blood of Steel Mill Operatives. J. Indust. Hyg. and Toxicology 11:329 (1929).

59. Miller, C. F. and J. W. Kerr, Field Notes on World War II German Fire Experience, S.R.I. Project MU-5070 (1965).

60. Sinclair. D., Stability of Aerosols and Behavior of Aerosol Particles. Ch. 5, Handbook on Aerosols. A.E.C. (1950), Reissued 1963.

61. Whytlaw-Gray and Patterson, Smoke. Edward Arnold and Company, London.

62. Engdahl, R. B., Combustion in Furnaces, Incinerators and Open Fires, Air Pollution, Ed. Arthur C. Stern, 2, p. 3 (1962).

63. Findeisen, W., Ueber das Absetzen kleiner, in der Luft suspendierter Teilchen in der menschlichen Lunge bei der Atmung, Pflugers Arch. Ges. Physiol. 236:367 (1935).

64. Dautrebande, L., Beckman, H. and W. Walkenhorst, Studies on Deposition of Submicronic Dust Particles in Respiratory Tract. A.M.A. Arch. Ind. Hlth. 19:383 (1959).

65. Desaga, H., Experimental Investigations of the Action of Dust. Ch. 13-B German Aviation Medicine WWII, 2:1188, U.S. Gov't. Ptg. Off. Washington, D. C. (1950).

66. Damann, H. G. and R. W. Bancroft, Toxicity of Ozone in High Altitude Flight. Advances in Chem. Ser. No. 21, 352 (1959).

67. Bioastronautics Data Book, p. 23, NASA SP-3006 (1964).

68. Adapted from Bioastron. Data Book, p. 22, Ed. Paul Webb, M.D. (Webb Assoc., Yellow Springs, Ohio) Scientific and Tech. Information Div. NASA.

69. Brooks, J. W., Evans, E. I., Ham, W. T., Jr. and J. D. Reid, The Influence of External Body Radiation on Mortality from Thermal Burns. Ann. Surg. 136:533 (1952).

70. Calif. Stds. for Ambient Air Quality and Motor Vehicle Exhaust. State of California Department of Public Health, Berkeley, California.

71. Amdur, M. O., Proc. 2nd Air Pollution Med. Res. Conf. (Calif. State Dept. of Public Health), Berkeley, 1958, p. 42. 1959.

72. Moureu, H., Chovin, P., Truffert, T., and J. Lebbe, rend. Acad. d. sc. 247:552 (1958).

73. Dean, R. D. and C. L. McGlothlen, The Effect of Environmental Stress Interactions on Performance. Aero-Space Div., Boeing Co, Seattle, Wn.

74. Newsom, B. D. and D. J. Kimeldorf, Alterations in Physiological Accommodation to Stress Induced by Irradiation. Aerospace Med. 34:226 (1963).

75. Baetjer, A. M., John Hopkins University RG 4505.

76. Evans, E. C., U.S.N.R.D.L. Personal Communication.

77. Training Requirements for Postattack Adaptive Behavior. Dunlap and Associates, Inc., Darien, Conn. AD 624 870.

78. Butler, C. P., U.S.N.R.D.L. Personal Communication.

79. Engdahl, R. B., Air Pollution, 2nd Ed., A. C. Stem, Academic Press, New York, 19:4, (1962).

80. Development of Fire Resistant Ratings for Shelter Components, OCD Work Unit 1132A, ITT Research Institute (March 1966).

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) ISOTOPES, INC. (formerly Hazleton-Nuclear Science Corporation) 4062 Fabian Street Palo Alto, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

DESIGN OF TESTS FOR THE EFFECTS OF
MASS FIRES ON SHELTER OCCUPENTS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

FINAL REPORT September 1966

5. AUTHOR(S) (Last name, first name, initial)

Lee, William (NMN) Jee, Cordell K.
Leong, Helen C. Hershberger, M. Gayle

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
26 September 1966	56	80

8a. CONTRACT OR GRANT NO. Contract No. NOO 228 66C0917 b. PROJECT NO. OCD Work Unit No. 1133B c. T. O. No. 65-200 (64) d.	9a. ORIGINATOR'S REPORT NUMBER(S) HNS-80 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) NRDL-TRC-67

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Civil Def United States Naval Radiological Defense Laboratory San Francisco 24, California

13. ABSTRACT

An outbreak of mass fires introduces serious additional life hazard factors which may require extensive modifications or overhaul of existing concepts of shelter design, construction and management. In this report the various life hazard factors associated with mass fires and the effects these would have on shelter occupants are discussed. Experiments (both field and supporting laboratory experiments) and facilities needed to more accurately determine or predict the effects of the various hazards on shelter occupants and for development and evaluation of protective measures are described. Basic biological test design considerations and certain precautions necessary in carrying out biological experiments are discussed.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Mass Fires						
Life Hazard Factors						
Shelter Design						
Shelter Construction						
Shelter Management						
Effects						
Shelter Occupants						
Experiments						
Field						
Facilities						
Protective Measures						
Biological Test Design						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ______________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ______________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ______________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.